CHARACTERISTICS AND ABSORPTION COEFFICIENT OF CO_2 LASER IN NATURAL GAS MIXTURES

By

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Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia in Fulfilment of the Requirement for the Degree of Master of Science

April 2006

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DEDICATION

To my beloved husband and son.

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirement for the degree of Master of Science

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Chairman: **Associate Professor Ir Norman Mariun, PhD**

Faculty: **Engineering**

This work was arranged to develop scientific and engineering database on the study of cw / repetitively pulsed CO_2 laser in terms of its characteristics and absorption coefficient in natural gas mixtures. The laser system is operated both in continuous wave mode as well as in pulse mode at 10.6μm wavelength range of infrared electromagnetic spectrum.

The study on CO_2 laser system consists of two parts. In the first part, the measurements on the characteristics of cw / repetitively pulsed CO_2 laser system are done at 10.6 μm wavelength. The output parameters of CO_2 laser are carried out in detail to determine the laser characteristics for getting maximum output energy and power subject to various variable such as pulse repetition rate, discharge current, duty cycle and pulse duration. Different aspects of CO_2 laser are studied to determine the laser characteristics between various design parameters and the effect of varying one parameter on others. The frequency and current

limits regarding maximum and minimum output energy and power are presented. The maximum pulse energy is achieved at 32mJ when the laser operated at 10mA discharge current with 50 Hz pulse repetition rate. A maximum power of about 11 watts is measured at a current of 10mA. The output energy and power is found to decrease with further increase in pulse repetition rate and discharge current. This is due to the saturation of the gas molecules inside the laser tube.

In the second part of the project, the experimental work on the absorption coefficient of CO_2 laser in compressed natural gas mixtures are measured at variable laser energy and pressures operated at 295K temperature. The measurements are done using optical transmission loss technique with 19% transmission loss due to the absorption by the optical system. The absorption data showed a strong dependence on both laser energy and pressure. It was found that natural gas mixtures absorb laser light the most, followed by pure natural gas and the lowest laser absorption coefficient is air. The results are found to follow the exponential law of absorption that is called as Beer-Lambert Law.

The purpose of this study is to explore the application of CO_2 laser especially in the area of combustion of natural gas. For the first step, the characteristics in terms of laser energy and power and its absorption in natural gas need to be studied.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Master Sains

CIRI-CIRI DAN PEMALAR PENYERAPAN LASER CO_2 DI DALAM CAMPURAN GAS ASLI

Oleh

NORHAFIDZAH BINTI MOHD SAAD

April 2006

Pengerusi: **Profesor Madya Ir Norman Mariun, PhD**

Fakulti: **Kejuruteraan**

Kajian ini bertujuan untuk membangunkan data-data saintifik dan kejuruteraan terhadap ciri-ciri sistem laser CO_2 serta pemalar penyerapan laser tersebut terhadap campuran gas asli. Sistem laser CO_2 yang beroperasi secara gelombang terus atau denyut berkala telah dilakukan pada panjang gelombang 10.6 μm pada spektrum electromagnet infra-merah.

Kajian ini terbahagi kepada dua bahagian. Pada bahagian pertama, kajian secara experimen ke atas ciri-ciri sistem laser CO_2 telah dilakukan. Parameter-parameter sistem laser tersebut dibincangkan secara mendalam bagi menentukan ciri-ciri laser bagi mendapatkan keluaran tenaga dan kuasa maksima yang bergantung kepada pelbagai pembolehubah seperti kadar pengulangan denyut, arus discas, tempoh denyut dan kitar tugas. Tenaga maksima diperolehi apabila laser

beroperasi pada arus 10mA dengan frekuensi 50Hz iaitu sebanyak 32mJ. Kuasa maksima pula diperolehi sebanyak 11 watt iaitu pada arus 10mA. Selepas melepasi nilai tenaga dan kuasa maksima tersebut, keluaran tenaga dan kuasa didapati berkurang dengan pertambahan frekuensi dan arus. Ini disebabkan molekul gas di dalam tiub laser menjadi tepu.

Pada bahagian kedua, pemalar penyerapan laser CO_2 di dalam campuran gas asli termampat diukur pada suhu 295K terhadap pembolehubah tenaga laser dan tekanan gas. Pengukuran dilakukan menggunakan teknik kehilangan penghantaran optik dengan andaian 19% kehilangan disebabkan penyerapan oleh sistem optik. Didapati campuran gas asli menyerap tenaga laser paling banyak, diikuti oleh gas asli dan udara. Keputusan yang diperolehi menepati peraturan penyerapan yang dikenali sebagai Hukum Beer-Lambert.

Tujuan kajian ini adalah untuk mengkaji penggunaan laser CO_2 terutama di dalam penyelidikan berkaitan pembakaran gas asli. Sebagai langkah pertama, ciri-ciri sistem laser CO_2 dan pemalar penyerapan terhadap gas asli perlu dikaji.

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First of all, with the humble gratitude, I would like to express my thanks and deepest praise to The Most Gracious and Most Merciful ALLAH Who has given me all strength, faith, confidence and patience to complete this project.

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I would like to express my appreciation to Kolej Universiti Kejuruteraan & Teknikal Malaysia (KUKTEM) for their generous financial support. Without them, this thesis would be a great burdon.

Finally, I would like to thank Universiti Putra Malaysia, my family and all my friends especially my husband, Muhammad Fadhil Abas for their support. I pray to Allah that He rewards each a bountiful reward.

I certify that an Examination Committee has met on 12 April 2006 to conduct the final examination of Norhafidzah binti Mohd Saad on her Master of Science thesis entitled "Characteristics and Absorption Coefficient of CO_2 Laser in Natural Gas Mixtures" in accordance with Universiti Pertanian Malaysia (Higher Degree) Act 1980 and Universiti Pertanian Malaysia (Higher Degree) Regulations 1981. The Committee recommends that the candidate be awarded the relevant degree. Members of the Examination Committee are as follow:

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This thesis submitted to the Senate of Universiti Putra Malaysia and has been accepted as fulfilment of the requirement for the degree of Master of Science. The members of the Supervisory Committee are as follows:

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Date:

DECLARATION

I hereby declare that the thesis is based on my original work except for quotations and citations, which have been duly acknowledge. I also declare that it has not been previously or concurrently submitted for any other degree at UPM or other institutions.

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NORHAFIDZAH BINTI MOHD SAAD

Date:

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LIST OF ABBREVIATIONS

B	rotational constant
c	velocity of light
CNG	compressed natural gas
CH_4	methane
cw	continuous wave
d	beam diameter
DC	duty cycle
DPDT	double poles double throw
E	laser energy
E_{abs}	absorbed laser energy
E_i	excitation energy
E_m	measured laser energy
E_r	rotational energy
E_{tr}	transmitted laser energy
E_{trans}	transition energy
E_v	vibrational energy
E_o	initial laser energy
FIR	far-infrared
F_{ph}	photon flux
F_E	electric field
f	focal length
g_i	Gaunt factor

HeNe	**Helium Neon**
h	**Planck's constant**
IR	**infrared**
I	**focal intensity**
I_{thr}	**threshold laser intensity**
k	**Boltzmanns's constant**
K_v	**absorption coefficient**
LNG	**liquefied natural gas**
l	**focal point length**
MIE	**minimum ignition energy**
n_e	**number of electron density**
n_{oi}	**population density of the *i*th ionic species**
P	**pressure**
P_{avg}	**average laser power**
P_{max}	**maximum laser power**
PRR	**pulse repetition rate**
PRT	**pulse repetition time**
r	**focal point radius**
S	**line strength**
t	**time**
T	**temperature**
v	**shock velocity**
Z	**partition function**
ZnSe	**zinc selenide**

$\Delta t_{1/2}$	**Pulse duration**
Φ	**equivalent ratio**
θ	**beam divergence**
λ	**laser wavelength**
α	**loss coefficient**
α_o	**small signal gain**
τ	**laser pulse duration**
τ_{FWHM}	**full width at half maximum (FWHM) pulse duration**
τ_o	**time at which $E(\tau_o) = E_{max}/e$, ($e = 2.7183$) calculated in equation (2.4.2)**